



Final Report

Project No: 262972

Project Acronym: BETs

Project Full Name: Propellantless deorbiting of space debris by bare electrodynamic tethers

Final Report

Period covered: from 01/11/2010 to 31/01/2014

Start date of project: 01/11/2010

Project coordinator name:
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Version: 1

Date of preparation: 10/09/2014

Date of submission (SESAM):

Project coordinator organisation name:
UNIVERSIDAD POLITECNICA DE MADRID

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PROJECT FINAL REPORT

Grant Agreement number:	262972
Project acronym:	BETs
Project title:	Propellantless deorbiting of space debris by bare electrodynamic tethers
Funding Scheme:	FP7-CP
Project starting date:	01/11/2010
Project end date:	31/01/2014
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Final Report

Please note that the contents of the Final Report can be found in the attachment.

4.1 Final publishable summary report

Executive Summary

Executive Summary

A Space tether is a thin, multi-kilometers long conductive wire, joining a satellite and some opposite end mass, and keeping vertical in orbit by the gravity-gradient. The ambient plasma, being highly conductive, is equipotential in its own co-moving frame. In the tether frame, in relative motion however, there is in the plasma a motional electric field of order of 100 V/km, product of (near) orbital velocity and geomagnetic field. The electromotive force established over the tether length allows plasma contactor devices to collect electrons at one polarized-positive (anodic) end and eject electrons at the opposite end, setting up a current along a standard, fully insulated tether. The Lorentz force exerted on the current by the geomagnetic field itself is always drag; this relies on just thermodynamics, like air drag.

The bare tether concept, introduced in 1992 at the Universidad Politécnica de Madrid (UPM), takes away the insulation and has electrons collected over the tether segment coming out polarized positive; the concept rests on 2D (Langmuir probe) current-collection in plasmas being greatly more efficient than 3D collection. A Plasma Contactor ejects electrons at the cathodic end. A bare tether with a thin-tape cross section has much greater perimeter and de-orbits much faster than a (corresponding) round bare tether of equal length and mass. Further, tethers being long and thin, they are prone to cuts by abundant small space debris, but BETs has shown that the tape has a probability of being cut per unit time smaller by more than one order of magnitude than the corresponding round tether (debris comparable to its width are much less abundant than debris comparable to the radius of the corresponding round tether). Also, the tape collects much more current, and de-orbits much faster, than a corresponding multi-line "tape" made of thin round wires cross-connected to survive debris cuts.

Tethers use a dissipative mechanism quite different from air drag and can de-orbit in just a few months; also, tape tethers are much lighter than round tethers of equal length and perimeter, which can capture equal current. The 3 disparate tape dimensions allow easily scalable design. Switching the cathodic Contactor off-on allows maneuvering to avoid catastrophic collisions with big tracked debris. Lorentz braking is as reliable as air drag. Tethers are still reasonably effective at high inclinations, where the motional field is small, because the geomagnetic field is not just a dipole along the Earth polar axis.

BETs is the EC FP7/Space Project 262972, financed in about 1.8 million euros, from 1 November 2010 to 31 January 2014, and carrying out RTD work on de-orbiting space debris. Coordinated by UPM, it has partners Università di Padova, ONERA-Toulouse, Colorado State University, SME Emxys, DLR-Bremen, and Fundación Tecnalia. BETs work involves 1) Designing, building, and ground-testing basic hardware subsystems Cathodic Plasma Contactor, Tether Deployment Mechanism, Power Control Module, and Tape with crosswise and lengthwise structure. 2) Testing current collection and verifying tether dynamical stability. 3) Preliminary design of tape dimensions for a generic mission, conducive to low system-to-satellite mass ratio and probability of cut by small debris, and ohmic-effects regime of tether current for fast de-orbiting. Reaching TRL 4-5, BETs appears ready for in-orbit demonstration.

Summary description of project context and objectives

Summary Description.

The LEO region (altitudes below 2,000 km) is becoming increasingly full with debris from over half a century of Space activity: defunct satellites, rocket bodies, fuel tanks, all kinds of subsystems, and smaller pieces from explosions and a continuous string of collisions. This is a risk for functioning satellites, and the International Space Station in particular, and may end making space useless. Using, say, films or ground/space lasers to de-orbit untrackable (<10 cm) debris, as it has

been suggested, is impractical. Just catastrophic collisions matter (over 40 KJoules Impact energy per kilogram of target). At relative speed of up to twice orbital velocity, kinetic energy per unit mass is much greater than energy per unit mass from TNT explosions. Two events account for 36 % of all catalogued (> 10 cm) debris and for 68 % of all big-debris conjunctions with derelict satellite Envisat: A Chinese missile hit Chinese satellite Fengyun-1C in 2007 / Russian Cosmos and American Iridium satellites collided in 2009. One catastrophic collision might occur every 6 to 12 years, collision probability increasing with frontal area, the number of fragments increasing with satellite mass. Large satellites at high-inclination, 800-1,000 km altitude orbits are critical.

Debris mitigation suggests mission design with minimum release of subsystems, immediate de-orbiting of upper-stage rockets, and Post-Mission Disposal (PMD) of satellites. Because satellites naturally orbit at altitudes where air drag is extremely weak, a dedicated de-orbiting system, beyond obvious rocket propulsion or drag augmented by deploying a sail, is required, but the case has been dragging on. This is partly due to the Kessler syndrome: debris flux models suggest that PMD will not avoid debris population to grow uncontrolled. Debris fragmentation would dominate debris elimination by re-entry into the lower atmosphere over most of the 11-year Solar Cycle. Active Debris Removal (ADR) is needed; cleaning what debris already exists. But this requires a second (Capture) technology, which is tougher than de-orbiting and raises legal issues. Furthermore, once space is cleaned, just one technology, PMD, will need be kept on. A repeatedly proved PMD technology could move the Inter Agency Space Debris Coordinating Committee, made of space-faring nations, to implement Active Debris Removal. Testing just de-orbit technology has thus become a priority matter.

There was one issue standing against any technology other than rockets for de-orbiting heavy space debris. Small satellites (well below 1 ton, say) fully burn at reentry but 10% to 40% of mass of large satellites (those of critical interest) survives reentry, and may result in damage to people if impact energy exceeds 15 Joules. Uncontrolled Reentry is only allowed if probability of damage on the ground is less than 0.0001; uncontrolled reentries in 2012 accounted for over 100 metric tons.

Risk level may be small, but re-entry anyway appeared to need rockets to end de-orbiting of heavy satellites. This could make technologies other than rockets useless for de-orbiting. Uncontrolled reentry is shallow (at 1 degree incidence) like a pebble skipping over a pond, with major break up occurring at about 80 km altitude. Place of impact is unpredictable and the footprint is thin but long. If reentry is controlled with rocket, incidence is about 20 degrees, footprint is small, and impact, predictable, is carried into the Pacific Ocean.

Recently introduced Design for Demise has eliminated the need for rocket controlled reentry, however. It involves analysis of materials, structures, and configuration, regarding processes of fragmentation, ablation, and fusion; also, passivation of power and propulsion subsystems. Rockets are now essential for neither de-orbiting nor reentry.

The BETs project is focused on a single but ambitious long term objective, proving that a de-orbit tether system of minimum complexity beats all other possible systems, whether propulsive (chemical, electrical) or just augmented drag, over a broad parameter domain, and this in fundamental metrics: low system-to-satellite mass ratio, fast de-orbiting and maneuverability, and high reliability, while surviving space debris throughout operation. The Project is determined to develop its concept onto Technology Readiness Level 4-5.

Intermediate objectives are:

- 1) Determining the survivability of a tape tether to debris and micrometeoroids. A tape might survive more effectively than a corresponding round tether due to the faster de-orbiting and to the disparate character of width and thickness. Proving this represents a fundamental result in tether technology. Both damage from single impacts by debris comparable to cross-section size and from multiple impacts by much smaller debris and micrometeoroids need be considered. Tests of hypervelocity impacts on foils at the Partner 2 facility will be also carried out.

- 2) Determining design criteria for sizing the three disparate dimensions of a tape tether, affecting mass, ohmic effects, current-collection regime, self-magnetic field, survivability against debris in space, under ambient conditions varying with de-orbit mission, and as the tether loses altitude (plasma density, geomagnetic field, relative orientation of field, orbital velocity, and tether geometry).

- 3) Determining the dynamical relevance of tether parameters such as tip mass, use of non-conductive segment, vis a vis the deployment requirements from light deployer-mechanism design. Studying the stability of tether oscillations as function of system parameters. Developing control laws, suitable for simple implementation, to stabilize oscillations in/off the orbital plane,

where passive stability might be marginal.

4) Determining a definite law for bare-tape current collection, taking into account ambient magnetic field and self-field, ion ram motion, and its orientation relative to a tape cross-section, and effects of electron adiabatic trapping arising from tether-rammed hypersonic ions that break quasi-neutrality over a front-region large compared with the Debye length. Both Particle-in-Cell, and alternatively Vlasov, numerical codes, will be carried out, results being compared to vacuum chamber tests.

5) Determining requirements on a long duration, years dormant, operation by a hollow cathode (HC). Requirements on operation over a broad range of emission current, low at the beginning of de-orbit mission and high near the end; conditions on HC systems capable of operating under varying flow rates; and operation under very low ambient plasma density. Estimating results from trade-off with the possible use of electron thermionic emission instead of a HC.

6) Determining requirements on control modules for high voltage/power operation under mass/volume limitations, posing severe conditions on magnetic components, power semiconductors, materials. Integrated magnetics design, DC/DC converter topologies, and power control methods under parallel-power processing architecture need be considered. Resulting knowhow in high voltage power systems with powers one order of magnitude above those in current use, might increase the project impact on other relevant space (and even industrial) applications.

7) Determining a passive deployment strategy for a conductive tape needing no retrieval; how to avoid jamming of a non-motorized wide tape. Consider end of a no-spin deployment with minimum tether libration, using a cold-gas jet and a leading plastic segment to help deployment till the gravity gradient takes over. The deployer itself might be ejected as part of the end mass.

8) Determining tape structure as regards materials, both cross-section wise and lengthwise, as with the leading plastic segment to help deployment; a bare conductive segment collecting current; and an insulated conductive segment next to the satellite. A triple-point (plasma and adjoining segments) with the bare conductive segment polarized negative with respect to the plasma might require smoothing the electric field at the junction to prevent arcing by use of a semiconductor sleeve.

Description of main S & T results/foregrounds

Scientific and Technological Results

1. Introduction

BETs Work-Package breakdown is made of 4 large Primary WPs: PWP10, PWP20, PWP30, and PWP40, and 3 simpler Primary PWPs: 50, 60, and 70.

PWP10. System Analysis and Trade-off is made of WP11 through WP15, involving:

11) Considerations on debris to determine a characteristic satellite/orbit to be considered in the project, and estimates of debris impact on tapes. 12) Plasma-Tether Interaction as constraint by both ambient plasma and orbit. 13) Tether dynamics on transitory effects under deployment, stability, and magnetic driving. 14) Effects on spacecraft dynamics (orbit/attitude) due to tether operation. 15) Tether current simulations and plasma chamber tests to determine/confirm a bare-tether current law.

PWP20. System Design is made of WP21 through WP23, involving design of 21) Tether, 22) Electrical Control and 23) Hollow Cathode systems, respectively. In turn, WP21 itself is made of WP211 through WP213, covering: a) Design of tape tether made of different segments and several foil materials; mechanical requirements on both electrical and mechanical operations. b) Deployment strategy. c) Deployment mechanism and end-mass design.

PWP30. System Manufacturing is made of WP31 through WP33, involving manufacturing of Tether, Electrical Control, and Hollow Cathode systems, respectively. In turn, WP 31 itself is made of WP311 and WP312, covering manufacturing of Tape and Deployment mechanism.

PPWP40. System Tests is made of WP41 through WP44, involving, Plasma chamber tests of current to the prototype tape, Tape Tests, Tests of deployment, and Hyper-velocity impact tests

PWP50. Analysis of Results is made of WP51 and WP52 on Assessment of compliance matrix, and Discussion of results

PWP60. Management is made of WP61 on Project management.

PWP70. Other Activities is made of WP71 through WP73, on Dissemination of Results-Protection of foreground, Impact on general public, and Internal private website-Link of Project components/Project Data Archive, respectively.

Work Packages 11, 12, 52, 61, and 71 are part of UPM work.

Work Packages 13, 14, 44, and 212 are part of UPD work.

Work Packages 15 and 41 are part of ONERA work.

Work Packages 23 and 33 correspond to CSU.
Work Packages 22, 32, 43, 51, 72, and 73 correspond to emxys.
Work Packages 213 and 312 correspond to DLR-Bremen.
Work Packages 42, 211, and 311 correspond to Tecnalía.

2. Results in Overall Design

A number of basic results were obtained at UPM.

1) A round bare tether had been commonly acknowledged as unable to survive de-orbiting under typical conditions. This had given rise to the concept of multi-line ‘tape’ made of thin round bare wires cross-connected to survive debris impacts, which had somehow been accepted as the solution to the tether survivability problem.

Independently, a real tape was shown previous to BETs to de-orbit much faster than the equivalent (equal mass / equal length) round tether. It was then shown in BETs that the fatal debris-impact rate was smaller than the rate for the equivalent round tether by more than one order of magnitude. Altogether, then, bare tape survival probability could be shown to be high under typical conditions. In addition, the real tape de-orbited much faster than the ‘fake tape’ multi-line tether.

2) Further, BETs showed that multiple impacts by tiny debris or by micrometeoroids exhibit a low accumulated-damage rate throughout the tape. Further, it was shown that greater damage, even if weak, was made by particles of either type at the largest size presenting multiple impacts. This paradoxical result was proved arising from a characteristic of the Poisson Probability Distribution, variance and mean are equal; at very low mean, relative fluctuations are high.

3) The dimensionless product of tether-to-satellite mass ratio and probability of a cut, which must be doubly small, could be written as an integral independent of time though dependent of ambient conditions along the de-orbit route; does also depend on w and on the ratio $L/h^{2/3}$ (L being tape length, w width, h thickness). This allows design on the geometry of the tape for an arbitrary mission.

A more thorough full code BETsMA was then developed. BETsMA is now an UPM Registered Design.

4) A direct Vlasov solver software (Kilaps), which both is non-stationary and allows for ram motion, which is able to exhibit electron trapping. Kilaps is now an UPM Registered Design.

3. Results in Dynamical Modelling

Tether dynamics and control and analysis of de-orbit performance required developing two new computer codes for the simulation of all three, dynamics, thermodynamics, and electrodynamics of bare tether systems, which differ mainly in complexity of tether flexibility modelling. Both models utilize up-to-date versions of the environmental routines in terms of ionospheric density (IRI-2007), atmospheric density (NRLMSISE-00) and magnetic field model (IGRF-2005). The gravity field is a 4x4 model that is more than sufficient for the purpose of this study. The atmospheric and ionospheric models are particularly heavy to run on a computer, what led to using the simplified code for tether motion, limited to libration dynamics, with the tether modelled as a rigid bar. The more accurate code retains the flexibility of the tether and its string dynamics, by lumped-mass modelling.

The analysis of control strategies proved that adoption of passive damping devices allows stabilizing the system dynamics throughout de-orbiting, without introducing the complexity of mechanical or electrical control. A passive rotational damper attached to the satellite and connected to the tether can provide a dissipation mechanism for the librational and flexural modes of the system. Stability is substantially improved by using negative stiffness in the rotational damper.

High inclination orbits, including the important slightly retrograde sun-synchronous orbits, are most challenging for an electrodynamic tether system (EDT) in de-orbiting. The efficiency of the EDT system decreases at high inclination due to the geometrical relationship between the tether and the magnetic field; this leads to long de-orbit times. The unfavorable geometry generates a smaller in-plane force component (the one that provides de-orbiting), and a greater out-of-plane force component that excites the tether dynamics. A special dynamics solution was found for polar orbits in which the out-of-plane oscillation was allowed to grow under the action of the out-of-plane component of the Lorentz force so as to increase the in-plane component of the Lorentz force, hence expediting substantially the de-orbiting process.

Hypervelocity testing of the tether samples provided by TECNALIA led to unique results, as hypervelocity shots on thin tapes are not available in the open literature. The 28 shots taken at the Aluminum and PEEK tether samples and the post-test analysis led to the derivation of ballistic limit equations that are specific to tapes. Tapes have very different damage behavior depending on the

angle of impact, exhibiting two regimes that are distinct between bore-side impacts and edge-on impacts.

4. Current Collection Issues

Anodic bare-tether contact relies on ambient electron collection by the tether itself. Plasma flow around the anode is however in a highly non trivial regime. Main interest lies in the flow of electrons in the anodic sheath, because they are carrying the current. Since there is no real analytical or semi-analytical model of this exacting regime, it is not surprising that comparison of experimental data to approximate models show no better agreement than typically a factor of two. The existence of slow ions created by charge exchange with residual neutrals in ground plasma tanks is also a possible source of error in that comparison. Special care was taken of plasma characterization since fast and slow ion populations must accurately reproduce tank conditions in simulations.

This issue is studied in the BETs project by both experimental and theoretical approaches. Modeling of the plasma was performed with the SPIS code using a full PIC (Particle-In-Cell) method, which clearly showed both the wake and the accumulation of ions upstream of the tether. Experiments were also conducted in ONERA's JONAS plasma tank. Several types of Langmuir probes are used at the same location to allow extracting both ion densities and electron parameters by computer modeling (classical Langmuir probe characteristics are not accurate enough in the present situation). A triple probe was also used for a more extensive characterization of the plasma in space and time dependent analysis.

The actual tether issued from BETs design is an assembly of bare tether segments made of different materials. Tests were carried out for different magnetic fields (compensated and non-compensated) and for different orientations of the tether with respect to the drifting velocity (perpendicular and parallel). As a broad conclusion, current collection without magnetic field is every time somewhat lower than predicted by the OML-regime current. The OML theory thus overestimates the current collection but little; when the magnetic field is zero or small. In the actual case of the geomagnetic field, collected current is about a factor of two smaller than the current predicted by the OML theory, though it must be considered that the environment density is not known with that precision. Further, any ohmic effects on the bare-tether current collection do reduce the dependence on electron density. The results of these tests will be presented in a paper at the Spacecraft Charging Conference in June 2014 at Pasadena, California.

5. Hollow Cathode Issues

The plasma contactor mostly considered for BETs is based on a discharge chamber that is driven by a hollow cathode, which is a tantalum tube that contains a low-work-function, impregnated, sintered tungsten insert. The discharge chamber makes the plasma contactor similar to an Ion Thruster, except that it has no charge-accelerating/decelerating grids. The hollow cathode tube is capped with an orifice plate on its center line. Tube and insert are heated to approximately 1100 oC by a resistive coil wrapped around the outside of the tube. The outside of the heater coil is thermally insulated with a multiple-layer, tantalum-foil radiation shield. The keeper is made of graphite and completely encloses the cathode except for an orifice located over the cathode orifice. The keeper orifice is 2.5 mm in diameter and is positioned ~1mm downstream of the cathode orifice plate.

The hollow cathode can also work without discharge chamber, which is introduced to avoid the appearance of double layers at high altitudes, where ambient electron density can be very small; that would lead to high drop voltages and reduced Contactor efficiency. The BETS Project discharge chamber equipped plasma contactor achieves enhanced plasma production, minimum expellant flows, and minimum impedance without reliance on the space plasma properties of the orbit or day-night cycle. The discharge chamber is made from mild steel and includes two magnetic rings made of samarium cobalt located on the inside of the chamber. The first ring is located near the exit of the ion source at one end of the cylindrical side wall, and the second is placed behind the cathode on the back plate.

Several hollow cathode assemblies (HCAs) were developed and extensively tested at CSU during the 3rd year of the BETs project in an effort to optimize the HCA design for hollow cathode plasma contactor (HCPC) systems. The optimization efforts focused on techniques to confine neutrals and enhance ionization rates nearby the cathode exit while simultaneously minimizing the mass of the HCA. A coupling voltage of only ~30V, - 40V was required to emit electron currents up to 18 A at a flow rate of only 2 sccm of xenon without any keeper or heater power input. This cathode can be started within a fraction of a second without the need for a heater, and could be used to simply a HCPC system. CSU will apply for a patent during April 2014.

6. Power Control Module issues

The power system handles the tether-injected energy and energizes the hollow cathode during the de-orbit maneuver. It has been designed to allow autonomous operation of the complete tether-cathode system once de-orbiting is started. The system relies on a completely decentralized regulated topology, with all different subsystems attached to a common DC bus, to allow their full control and to readily respond to expected fast transients of the electrodynamic tether.

The main components of the power system are: * A DC/DC converter that powers the DC bus while the system is in stand-by, so as to keep the battery charged and keep it controlled through the satellite telecommand and telemetry bus (TM/TC). * A battery maintained charged in order to achieve autonomous operation of the system. When the system is in stand-by, the battery is maintained in trickle charge by using a charge regulator (BCR) that extracts power from the DC bus. While in operation, a battery discharge regulator (BDR) maintains the voltage of the DC bus. * A resonant stage that powers the hollow cathode with different voltages from the DC bus of the system. * A step-up converter that gets the energy from the electrodynamic tether and injects it into the DC bus to be used for battery charging and powering the hollow cathode. * A dump resistor that dissipates excess of energy produced by the hollow cathode while in operation. * A main error amplifier that harmonizes the operation of all the mentioned subsystems by implementing a 3-domain control.

There are four working modes in the system, one when the satellite is in its operational life and the tether system in stand-by, and the other three when the satellite is being decommissioned by the electrodynamic tether. The decision of being in stand-by or de-orbiting is handled by the TM/TC in coordination with the satellite on board computer (OBC). While in standby the main error amplifier operates the DC/DC converter and the BCR that maintains the battery fully charged. While de-orbiting the main error amplifier voltage determines in which of the three operational modes is the power system working in and what subsystem is regulating the DC bus:

* Dump mode: the battery is fully charged and the tether provides more energy than needed to power the hollow cathode. The dump resistance enters into operation to dissipate the excess of power and its operation regulates the DC bus.

* BCR mode: the battery is charging from the energy provided by the tether, which supplies power to the hollow cathode as well. The BCR regulates the DC bus.

* BDR mode: battery and tether supply the hollow cathode because not enough power comes from the tether. The BDR regulates the DC bus in this situation.

The usual techniques for reliability and single point failure-free design allow the production of satellite flight hardware following the described topology.

7. Deployment-Mechanism Design issues

Deployer design was driven by the main goal of creating a completely passive unreeling mechanism that can be implemented in every satellite system without requiring big modifications. This goal can be reached with a stand-alone design in which just one signal is needed, after the satellite reaches its end of life, to start deployment of the tether. Because of this, unreeling proceeds with no control from the satellite on-board data-handling system and with no power supply. Originally both reel design and the Origami deployment used in JAXA's limited T-Rex suborbital mission had been considered

In a first design phase DLR carried out a state-of-the-art survey, to help in attaining an overview of existing deployers, as well as an estimate of environmental parameters affecting deployment functionality. Based on DLR experience in deploying small electro conductive tethers and a flat cable on planetary surfaces, up to seven different concepts were developed and evaluated, and realized in bread-board units to perform deployment tests under a variety of conditions, considering required pull force at tether release and deployment behaviour.

The result of the deployment tests show that deployment from a reel appears to less affect deployment behaviour, such as possibly leading to failure. Entanglement risk was the lowest and no tether twisting occurred. For the deployment of the tether the end-mass on the front will be ejected smoothly with separation springs to pull the tether from the reel. Due to both the constancy of angular momentum and the decreased tether-coil diameter, the unreeling speed increases as deployment proceeds. To ensure that tether unreeling speed does not exceed a predetermined value, a centrifugal break is set up on the rotation axis. For the connection between tether and hollow cathode a slip ring is used. DLR does consider applying for a patent on the deployment mechanism.

Considering full scale missions with tether lengths of the order of 10 km, say, the increase in diameter of the tether reel may compromise the requirement of universal use irrespective of satellite. To overcome this drawback, the entire tether length can be distributed over several reels. In this way,

the overall reel diameter can be kept in check, with just the full reel-system height increasing.

8. Tape Structure Issues

Different materials and different tether-design alternatives were considered by TecNALIA, with info from both the ProSEDS (Propulsive-SEDS) and T-Rex (Tyrannosaurus-Rex) missions, both intended to test bare-tether collection. Particularly considered was the T-Rex tape, made of a PET resin layer sandwiched between two aluminium layers. Possible heating issues in the sandwich glue, led finally to a design with a complex longitudinal structure, basically made of two pure bare aluminium and pure plastic (PEEK) segments. Their junction is achieved by a Joint enclosing Al and PEEK within two PEEK layers. The conductive segment presents an insulated segment next to the deployer. This resulted in a triple point junction (ambient plasma and bare and insulated aluminium segments), which may result in arcing if bias is locally negative with respect to plasma; the known solution is to enclose the junction in a semi-conductor sleeve.

Multiple tests were carried out at TECNALIA facilities with the aim of validating and making sure that the designed/manufactured tape tether fulfills the required specification detailed in the compliance matrix. These tests have been made at different temperatures, and after a thermal cycling process, as in this project the tape tether would be orbiting the Earth in LEO, reaching different temperature ranges. The simulation was carried out with the finite difference method (FDM) by TK thermal software. A process of ageing has been realized in the thermal camera, using three different curves for the three different samples: 382 cycles for the PEEK samples, 260 cycles for the aluminum samples, and 320 cycles for the PEEK and aluminium Joint.

Once the samples came out the climatic chamber, maximum tensile tests were performed at different temperatures, PEEK at -70°C and -43°C, AL 1100H19 at -53°C and 228°C and the Joint at -70°C and room temperature. The maximum tensile strength supported by PEEK at -43°C doubled the required value of maximum tensile strength specified by ESA. Tensile strength was larger at -70°C, as expected from plastic material.

Test results for the Joint were quite satisfactory. Results AL 1100H19 were similarly satisfactory at -53°C. That was not so at 228°C, the aluminum sample did not reach the minimum load of 100N required by ESA. However, the too high security factor = 5 allows to keep this Aluminium 1100H19.

Potential impact and main dissemination activities and exploitation results

Potential Impact

International Impact on Policies

The project, if successful in results, will allow 'preventing generation of new debris and de-orbiting upper stages and spacecraft after mission completion' as required by the EC in its Call, in relation to the topic in question. The Project would provide an efficient de-orbit system to be carried in the future by every launched spacecraft and having a mixed character, being basically passive and simple like (enhanced) air drag, but also propulsive like rockets and electrical thrusters. This might first have an important political impact.

The increase in the number of countries with direct access to space makes the present approach to the debris problem not just European as against national or local, but fully international in character. Related research activities do naturally present a world scale. Guidelines from the United Nations, through its Committee on the Peaceful Uses of Outer Space (COPUOS), and from national space agencies through the Inter-Agency Debris Coordination Committee (IADC), emphasize mitigation measures, in addition to Active Debris Removal.

Steps will be needed to bring about the impact of a Project as here proposed. The Coordinator made a formal presentation of BETs at the COPUOS Scientific and Technical Subcommittee meeting in Vienna, on February 14, 2014; an interview with him will head the May issue, centered on space debris, of the EU Research*eu Results Magazine. Political difficulties may determine whether a full international impact will be achieved. To guarantee an effective implementation of de-orbiting new satellites at end of life, an international consensus is required, in effect resting on UN space governance. Ultimately, the Project could nonetheless have a social success comparable to its commercial one. It could certainly lead to exploitation of leading-edge technology by companies in Europe.

Dissemination Activities and Exploitation of Results

Dissemination of Project results would take place at two levels:

a) Specialized audience, policy makers, and industry

BETs dissemination actions have been mainly targeted to scientific community and industry. Following Dissemination Guidelines for FP7 Projects, relevant results have been published in specialized journals and presented in workshops and conferences. These dissemination results ensure that attained knowledge and exploitable foreground will benefit the entire society and avoid duplication of research. UPM and emxys (responsible of BETs website) led different actions to explain the bare-tether concept and how the BETs Consortium made progress in its technological development. Partners gave visibility to their own results in specialized forums, including publication in a range of journals and participation in proper meetings and conferences.

BETs results already yielded 11 papers published in specialized peer-review journals. Additionally, 4 manuscripts are currently under revision and 3 will be submitted immediately after BETs end. A total of 27 presentations in international congresses were carried out. Many of the works were published in proceedings of conferences. Two book chapters completed the written BETs dissemination activities directed towards scientific community and industry. These activities were mainly focused on tether-plasma interactions, mission design, tether survivability models, plasma contactor technology, and numerical simulations of tether deployment and dynamics. They extended tether knowledge and spread out the bare-tether concept among the space debris community.

UPM attended the FP7 Space Conferences in Budapest (2011) and Larnaca (2012). In April 22-25 (2012) UPM and UNIPD attended the Sixth European Conference on Space Debris at ESA/ESOC. In December 18th (2012) the Coordinator made a presentation at ESA/ESTEC. BETs researchers made presentations or industrial exhibitions at the 61, 62, and 63 International Astronautical Congresses in 2011, 2012, and 2013. Those activities presented the progress of the Consortium as a whole and a global perspective on the state-of-the-art in tether technology. They gave the opportunity to explain the BETs project to an audience not related with the bare tether concept, in particular to policy makers and industry. The Coordinator will make an invited presentation on BETs at the 14th SCTC, at the NASA Jet Propulsion Lab, next June 23-24.

Since transfer of knowledge and training of young scientists is important to guarantee the future of tether technology, the Bets Consortium arranged the collaboration of several students. Seven PhD thesis, 3 master thesis, and 5 collaborations with undergraduate students were carried out during the project. Five PhD students made visits of several months duration to other BETs partners, thus improving their training, the quality of their thesis, and Consortium networking.

BETs attended the II Curso de Comercialización de Tecnologías de la UPM, Innovatech, a 44 hours course organized by UPM. In the last session, participants presented their own technologies with a jury made of possible investors. The bare electrodynamics tether concept and two additional UPM technologies were selected among 20 competitors. The three winners presented their technologies again in the First UPM Innovatech International Workshop in Madrid with an audience of international investors. A product of this course is the Innovatech technical sheets, which may help disseminate the BETsMA code (a software developed by UPM).

a) General public

A BETs dissemination goal was to make the entire society aware of the space debris problem. BETs delivered a clear message: current space human activity model is not sustainable. It was then followed by an explanation about how science, in particular electromagnetism and plasma physics, can provide a light and reliable technological solution (electrodynamic tethers). These two ideas highlight the importance of the research and the innovation activities to our lives and the important role played by the European Commission programmes. Many of BETs dissemination activities were directed toward undergraduate students from ETSI Aeronáuticos (UPM). At the end of the activities they recognized the importance of general physics courses (like electromagnetism or classical mechanics) in the development of space technologies.

UPM organized activities in XII (2012) and XIII (2013) Semana de la Ciencia de Madrid, a yearly Science Fair. The exhibitions included flyers, posters, hardware provided by the partners, videos, and interactive experiments. The visitors understood the space debris problem, the BETs project, and the physics underlying the bare tether concept. Thanks to the experiments, they were able to experience the Lorentz drag, which is responsible for deorbiting of the satellite. In 2013, BETsMA, a tether flight simulator developed by UPM, was included in the exhibition and visitors designed their own tether missions in the fair. ETSIA students found the simulator very interesting; they discovered how fundamental concepts learned in different courses were integrated in the same numerical tool. A group of high school students also attended the fair in 2013. Thanks to the success of the exhibition, it will be continued in next editions of Semana de la Ciencia, beyond BETs. Product of the

organization of these exhibitions is a set of educational material, which has been used by professors in the University afterwards. In particular, BETs experiments have been used in General Physics II, a first year 1-semester course at ETSI Aeronáuticos.

UPM gave a talk about the BETs project and the space debris problem in the European Space Expo 2013 in Madrid. A group of students from the ETSI Aeronáuticos, guided by BETs, visited the fair. Two additional presentations in 2013, one in cooperation with the NGO named ONGawa and the second in the III Seminario sobre Actividades Espaciales y Derecho, complete the list of talks given by UPM and targeted to the general public.

BETs press releases included 3 communications made by Gabinete de Prensa de Comunicación of ETSIA, two interviews in communications media El Mundo and El Confidencial, and an article in the UPM Innovatech Research Newsletter. Other media and blogs mentioned the BETs project and its web page, and gave links to related tether news. The AIAA magazine Aerospace America gave news about BETs in the December issues of 2011, 2012, and 2013. A long radio interview at CienciaEs.com, within a program named Hablando con Científicos, gave the opportunity to explain the space debris problem and the tether solution. About 10,000 people downloaded the interview from the web site just the first week after uploading.

The BETs official web page offers information about the project, the partners, and the progress made by the Consortium. Activities, like international congresses attendance or science fair organization, are announced in the blog. The list of publications is updated regularly. A promotional video and information about two pieces of software developed by the Consortium will be uploaded immediately following BETs end.

Protection and Exploitation of results

In the Sixth European Conference on Space Debris at ESA/ESOC (2012), the BETs Consortium was contacted by V. Gómez Molinero, CTO from Airbus Defense & Space Spain. Mr Gomez manifested his interest in electrodynamics tethers. Several contacts and meetings between BETs-UPM and Mr. Gómez took place afterwards. At the BETs Final Meeting in Madrid (January 2014), Mr. Gomez made a presentation to the BETs Consortium about a possible collaboration in the next H2020 call. Airbus could be interested in the use of bare electrodynamics tether for de-orbiting the Multiple Payload Dispensers in the VESPA or Soyuz Fregat launchers. He offered himself to sound off Arianespace for that purpose. Mr M. Bezdenejnykh, Mr Gomez's collaborator from Airbus, started the preliminary design of such a demonstration mission supervised by Dr. G. Sánchez-Arriaga (UPM). A meeting with Arianespace is planned in the spring of 2014.

Besides a demonstration mission, which would make tether technology ready for its commercial use, BETs produced exploitable results. They cover metallic materials, electrical system, plasma contactor technology, spacecraft-plasma interactions software and tether flight simulators. In the BETs, January 2014, Madrid meeting, the Consortium agreed to keep most of the advances protected by industrial secret. Each partner will decide whether the technology or part of it will be protected by other methods, like patents or software registry. Project publications and communications were prepared to be compatible with future protection actions.

CSU designed, manufactured and tested a Plasma Contactor. Important progress on the hollow cathode subsystem mass, power, and voltage versus intensity performance were achieved. CSU is currently trying to protect these advances and a patent will be filed by April 26th.

In WP15 the Spacecraft Plasma Interaction Software (SPIS - <http://dev.spis.org>) was used to simulate tether current collection. Some code developments on the time integration scheme were developed. This led to a contribution by ONERA to the SPIS numerical solver. As SPIS is an open source project, these contributions have been publicly released in the last SPIS version (i.e., SPIS 5.1). The version has been registered with the reference IDN.FR.001.390021.001.R.P.2011.000.31235 on 31/10/2013 and is publicly released in an open source license on the SPIS website. The owners of the intellectual property are ONERA for the numerical solvers and Artemum for the user interface. The contribution of the BETs project in the ONERA IP is less than 1% of the deposited code.

Two software codes were developed by UPM

- BETsMA. Bare Electrodynamics Tether Mission Analysis. Sánchez-Arriaga, G., Khan, B., Sánchez-Torres, A., Williams, J. D., Blash, D., García de Quirós, F., Carrasco, J. A., Rosta, R. (WP52.Task-1)
 - Kilaps. Kinetic Langmuir Probe Software. Sánchez-Arriaga, G., Pastor-Moreno, D. (WP12.Task-3)
- Both codes were submitted to OTRI (UPM software registering office). After protection, UPM will

sell licenses to interested institutions and companies.

BETsMA, which is based on analysis (WP52.Task-1) to be presented at the 14th SCTC, next June 23-27, aims at preliminary mission analysis using bare electrodynamic tethers. Experts and beginners on tethers will find the optimum tether system for a given deorbiting mission. The software provides the main figures of merit, including deorbit time, mass of the subsystems, satellite trajectory and tether survival probability among others. Its friendly user interface has been designed for quick parametric studies in a broad range of orbital and tether conditions. Since a broad audience will be able to compute the cost of the missions, BETs Consortium estimates that BETsMA may help to make popular bare tethers as a deorbiting device. BETsMA technical sheets can be found at the UPM website

<http://www.upm.es/observatorio/vi/index.jsp?pageac=innovacion/>

A manual of BETsMA will be available at the project web site after the registering process.

Kilaps is the first non-stationary direct Vlasov code to study current collection by cylindrical Langmuir probes. As opposed to stationary codes, Kilaps is able to capture particle trapping. A direct Vlasov code, unlike particle-in-cell (PIC) codes, is free of numerical noise. Kilaps is a valuable numerical tool for experts on current collection and plasma-spacecraft interaction. Its confrontation with more popular PIC codes can help stimulate development of plasma-spacecraft interaction numerical tools.

Address of project public website and relevant contact details

<http://www.thebetsproject.com/>

4.2 Use and dissemination of foreground

Section A (public)

Publications

LIST OF SCIENTIFIC PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
No.	Title / DOI	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Is open access provided to this publication ?	Type
1	Survival Probability of Round and Tape Tethers Against Debris Impact 10.2514/1.A32383	Shaker Bayajid Khan , Juan R. Sanmartin	Journal of Spacecraft and Rockets	Vol. 50/Issue 3	American Institute of Aeronautics and Astronautics Inc. (AIAA)	United States	01/02/2014	603-608	No	Peer reviewed
2	Low Work-Function Coating for an Entirely Propellantless Bare Electrodynamic Tether 10.1109/TPS.2012.2189589	John D. Williams , Juan R. Sanmartin , Lauren P. R and	IEEE Transactions on Plasma Science	Vol. 40/Issue 5	Institute of Electrical and Electronics Engineers Inc.	United States	01/05/2012	1441-1445	No	Peer reviewed
3	Drifting Plasma Collection by a Positive Biased Tether Wire in LEO-Like Plasma Conditions: Current Measurement and Plasma Diagnostic 10.1109/TPS.2013.2257871	Jean-Michel Siguier , Pierre Sarrailh , Jean-Francois Roussel , Virginie Inguimbert , Gael Murat , Juan SanMartín	IEEE Transactions on Plasma Science	Vol. 41/Issue 12	Institute of Electrical and Electronics Engineers Inc.	United States	01/12/2013	3380-3386	No	Peer reviewed
4	Deorbiting Performance of Bare Electrodynamic Tethers in Inclined Orbits 10.2514/1.58428	Claudio Bombardelli , Denis Zanutto , Enrico Lorenzini	Journal of Guidance, Control, and Dynamics	Vol. 36/Issue 5	American Institute of Aeronautics and Astronautics Inc. (AIAA)	United States	01/09/2013	1550-1556	No	Peer reviewed

5	A direct Vlasov code to study the non-stationary current collection by a cylindrical Langmuir probe 10.1063/1.477 4398	G. Sánchez-Arriaga	Physics of Plasmas	Vol. 20/Issue 1	American Institute of Physics Inc.	United States	01/01/2013	013504	No	Peer reviewed
6	Bare-tether cathodic contact through the resonant emission by low-work-function materials 10.1063/1.473 6987	Xin Chen , J. R. Sanmartín	Physics of Plasmas	Vol. 19/Issue 7	American Institute of Physics Inc.	United States	01/01/2012	073508	No	Peer reviewed
7	Analysis of tape tether survival in LEO against orbital debris http://dx.doi.org/10.1016/j.asr.2014.02.008	Shaker Bayajid Khan , Juan R. Sanmartín	Advances in Space Research	in press	Elsevier Limited	United Kingdom	01/02/2014	in press	No	Peer reviewed
8	Current-voltage characteristics of a cathodic plasma contactor with discharge chamber for application to electrodynamic tether propulsion	K. Xie, R. Martinez and J. Williams	Journal of Physics D - Applied Physics	in press	Institute of Physics Publishing		01/04/2014	in press	No	Peer reviewed
9	Relativistic current collection by a cylindrical Langmuir probe 10.1063/1.472 9662	G. Sánchez-Arriaga , J. R. Sanmartín	Physics of Plasmas	Vol. 19/Issue 6	American Institute of Physics Inc.	United States	01/01/2012	063506	No	Peer reviewed
	BETs: Propellantless deorbiting of space debris by bare electrodynamic tethers	Sanmartín, J. R., Charro, M., Lorenzini, E. C., Colombatti, G., Roussel, J. F., Sarrailh, P., Williams, J. D., Xie, K., García de Quirós, F., Carrasco, J. A., Rosta, R., Zost, T., Lasa, J., Marcos, J.	Let's embrace space	II	Publications Office of the European Union		01/01/2012	506-513	Yes	Article
	Seguridad Espacial: Una solución práctica para el problema de los residuos espaciales en órbita	Sanmartín, J. R., Sánchez-Arriaga, G	III Seminario sobre Actividades Espaciales y Derecho				21/11/2013	69-82	No	Article
	Hollow Cathode With Low Work Function Electride Insert	Lauren P. Rand , Ryne	Volume 1: Advances in Aerospace Technology; Energy Water Nexus; Globalization		ASME		01/01/2011	317-323	No	Conference

	10.1115/IMECE 2011-65785	M. Waggoner, John D. Williams	Journal of Engineering; Posters							
	Electrodynamics Tethers for Deorbiting Maneuvers	D. Zanutto, G. Colombatti and E.C. Lorenzini	CEAS 2011 Post-Conference Proceedings		Confined. Monghidoro (BO) Italy		24/10/2011		No	Conference
	Bare-tether cathodic contact through the resonant emission by low-W materials	Chen, X. and Sanmartín, J	39th EPS Conference on Plasma Physics Vol. 36F		European Physical Society		02/07/2011		No	Conference
	Orbital Debris Mitigation through Deorbiting with Passive Electrodynamics Drag	D. Zanutto, E. C. Lorenzini, R. Mantellato, G. Colombatti, A. Sanchez-Torres	63rd International Astronautical Congress 2012 (IAC 2012)		International Astronautical Federation		01/10/2012		No	Conference
	Tether de-orbiting of satellites at end of mission	Sanmartín, Juan R.; Sánchez-Torres, Antonio	39th COSPAR Scientific Assembly Abstract C3.1-12-12, p.1670		Committee on Space Research		14/07/2012		No	Conference
	Tape-Tether Design For De-Orbiting From Given Altitude And Inclination	Sanmartín, J. R., Sánchez-Torres, A., Khan, S. B., Sánchez-Arriaga, G., Charro, M.	Sixth European Conference on Space Debris, ESA/ESOC		ESA Communications		22/04/2013		No	Conference
	Survivability to Hypervelocity Impacts of Electrodynamics Tape Tethers for Deorbiting Spacecraft in LEO	A. Francesconi, C. Giacomuzzo, F. Branz, E.C. Lorenzini	Sixth European Conference		ESA Communications		22/04/2013		No	Conference
	Deorbiting of Spacecraft at the End of Life with Electrodynamics Tethers Stabilized by Passive Oscillation Dampers	R. Mantellato, M. Pertile, G. Colombatti, A. Valmorbidà, E. C. Lorenzini	PROCEEDINGS of the 4th CEAS conference in Linköping, 2013		Linköping University Electronic Press		16/09/2013		No	Conference
	Analysis of Passive System to Damp the Libration of Electrodynamics Tethers for Deorbiting 10.2514/MSPAC E13	R. Mantellato, M. Pertile, G. Colombatti, E. C. Lorenzini	AIAA SPACE 2013 Conference and Exposition		American Institute of Aeronautics and Astronautics	Reston, Virginia	10/09/2013		No	Conference

	Instant Start Electride Hollow Cathode	Rand, L., and Williams, J.	The 33rd International Electric Propulsion Conference		The Electric Rocket Propulsion Society		06/09/2013		No	Conference
	Effect of a Low Work Function Insert on Hollow Cathode Temperature and Operation 10.2514/MJPC13	Rand, L., and J. Williams	49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference		American Institute of Aeronautics and Astronautics	Reston, Virginia	14/07/2013		No	Conference
	Electrodynamic tethers for planetary and de-orbiting missions	A. Sánchez-Torres			Universidad Politécnica de Madrid		19/07/2013		Yes	Thesis
	Analysis of Propellantless Tethered System for the De-Orbiting of Satellites at End of Life	D. Zanutto			Università di Padova		18/01/2013		Yes	Thesis
	The effects of a realistic hollow cathode plasma contactor model on the simulation of bare electrodynamic tether systems	D. Blash			COLORADO STATE UNIVERSITY		04/10/2013		Yes	Thesis
	An Calcium Aluminate Electride Hollow Cathode	P. R. Lauren			Colorado State University		20/02/2014		Yes	Thesis
	Development of a system for passive damping of tethered satellites dynamics	N. Sullo			Università di Padova		07/12/2012		Yes	Thesis
	Analysis of Electrodynamic Tether Systems for Propellantless Deorbiting Maneuvers	R. Favaretto			Università di Padova		15/12/2010		Yes	Thesis

LIST OF DISSEMINATION ACTIVITIES								
No.	Type of activities	Main Leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	Propellantless deorbiting of space debris by bare electrodynamic	14/02/2014	Scientific-Technical Subcommittee, United Nations Committee on the Pacific Uses of Outer Space	Scientific community (higher education, Research) - Policy makers		United Nations Countries
2	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	Propellantless deorbiting of space debris by bare electrodynamic tethers	18/12/2012	ESA/ESTEC Presentation	Scientific community (higher education, Research)		European Countries
3	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	Propellantless deorbiting of space debris by bare electrodynamic tethers	12/05/2011	FP7/Space Conference Budapest, Hungary	Scientific community (higher education, Research) - Industry - Medias		European Countries
4	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	Propellantless deorbiting of space debris by bare electrodynamic tethers	15/11/2012	2nd FP7 Space Conference, Larnaca, Chipre	Scientific community (higher education, Research) - Policy makers		European Countries
5	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	BETs progress in state-of-the-art tether technology	17/09/2012	CleanSpace Workshop (ESA/ESOC)	Scientific community (higher education, Research) - Policy makers		European Countries
6	Press releases	UNIVERSIDAD POLITECNICA DE MADRID	Experimentar el deorbitado espacial	02/11/2012	ETSI Aeronauticos web page	Civil society		Spain
7	Press releases	UNIVERSIDAD POLITECNICA DE MADRID	Eliminación de basura espacial mediante amarras electrodinámicas	13/02/2013	ETSI Aeronáuticos web page	Civil society		Spain
8	Press releases	UNIVERSIDAD POLITECNICA DE MADRID	Un paso más cerca del fin de la basura espacial	03/03/2014	ETSI Aeronáuticos web page	Civil society		Spain
9	Press releases	UNIVERSIDAD POLITECNICA DE MADRID	BETsMA. Soluciones para 6000 toneladas de basura espacial	19/02/2014	UPM Innovatech Newsletter	Industry		Spain

10	Oral presentation to a wider public	UNIVERSIDAD POLITECNICA DE MADRID	BETsMA: Deorbiting space debris with one click	04/12/2013	1st UPM innovat ech International Workshop	Industry		Europe and EEUU
11	Exhibitions	UNIVERSIDAD POLITECNICA DE MADRID	Amarras Conductoras espaciales para deorbitar satélites al finalizar su misión	13/11/2012	XII Semana de la Ciencia de Madrid (ETSI Aeronáuticos)	Civil society		Spain
12	Exhibitions	UNIVERSIDAD POLITECNICA DE MADRID	Amarras Conductoras espaciales para deorbitar satélites al finalizar su misión	13/11/2013	XIII Semana de la Ciencia de Madrid (ETSI Aeronáuticos)	Civil society		Spain
13	Oral presentation to a wider public	UNIVERSIDAD POLITECNICA DE MADRID	Eliminación de basura espacial	16/02/2013	European Space Expo	Civil society		Spain
14	Oral presentation to a wider public	UNIVERSIDAD POLITECNICA DE MADRID	Amarras espaciales conductoras para eliminar basura espacial	08/03/2013	ETSI Aeronáuticos	Civil society		Spain
15	Oral presentation to a wider public	UNIVERSIDAD POLITECNICA DE MADRID	Seguridad espacial: una solución práctica para el problema de los residuos espaciales en órbita	20/11/2013	ETSI Aeronáuticos	Scientific community (higher education, Research) - Industry - Civil society		Spain
16	Interviews	UNIVERSIDAD POLITECNICA DE MADRID	Hablando con Científicos	14/03/2014	http://ciencias.es.com/	Scientific community (higher education, Research) - Civil society		Spain and South America
17	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	Propellantless deorbiting of space debris by bare electrodynamic tethers	03/10/2011	International Astronautical Congress, Cape Town, South Africa	Scientific community (higher education, Research)		International Conference
18	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	A comparative analysis of survival probability of round and thin-tape tethers of equal mass and length against debris impact	14/07/2012	39 COSPAR Scientific Assembly, Mysore, India	Scientific community (higher education, Research)		International Conference
19	Oral presentation to a scientific event	OFFICE NATIONAL D'ETUDES ET DE RECH	LEO drifting plasma collection by a positive biased tether	14/05/2012	12th Spacecraft Charging Technology Conference,	Scientific community (higher education, Research)		International Conference

		ERCHES AER OSPATIALES	wire: current measur ement and plasma diagnostic		Kitakyushu, Japan			
20	Oral presentation to a scientific event	OFFICE NAT IONAL D'ETUDES ET DE RECH ERCHES AER OSPATIALES	LEO drifting plasma collection by a posi tive biased tether w ire: time-dependent simulations using SP IS	14/05/2012	12th Spacecraft Charging Techn ology Conference, Kitakyushu, Japan	Scientific comm unity (higher educat ion, Research)		International C onference
21	Oral presentation to a scientific event	UNIVERSIDAD POLITECNICA DE MADRID	Direct Vlasov s imulations of non-St ationary cylindrical Langmuir probes in flowing plasmas	10/07/2013	International W orkshop in Electric Probes	Scientific comm unity (higher educat ion, Research)		International C onference
22	Posters	UNIVERSIDAD POLITECNICA DE MADRID	Debris mitigation by electrodynamic teth ers previous to Acti ve Debris Removal	11/12/2013	Countdown to Ho rizon 2020 Space, Brussels	Industry		European Countries
23	Flyers	UNIVERSIDAD POLITECNICA DE MADRID	Amarras espaciales para eliminar basura espacial	13/11/2013	ETSI Aeronáuticos	Civil society		Spain
24	Web sites/Appli cations	EMBEDDED I NSTRUMENTS AND SYSTEMS S. L	The bare electr odynamic tether proj ect	16/06/2011	http://www.theb etsproject.com/	Scientific comm unity (higher educat ion, Research) - Ind ustry - Civil society - Policy makers - Medias		Web site
25	Exhibitions	EMBEDDED I NSTRUMENTS AND SYSTEMS S. L	BETs Promotional material display	03/07/2011	62nd International Astronautical Co ngress, Cape Town, South Africa	Scientific comm unity (higher educat ion, Research) - Ind ustry		International C onference
26	Exhibitions	EMBEDDED I NSTRUMENTS AND SYSTEMS S. L	63nd International A stronautical Congres s	01/05/2012	62nd International Astronautical Co ngress,, Naples, Ita ly	Scientific comm unity (higher educat ion, Research) - Ind ustry		International C ongress
27	Press releases	EMBEDDED I NSTRUMENTS AND SYSTEMS S. L	Crear Satélite con c erebro para limpiar la basura espacial	24/02/2013	Periódico El Mu ndo	Civil society		Spain
28	Press releases	UNIVERSIDAD POLITECNICA DE	BETs, la solución "made in Spain" al	18/02/2013	Peiródico El Co nfidencial	Civil society		Spain

		MADRID	dilema de la basura espacial					
29	Press releases	UNIVERSIDAD POLITECNICA DE MADRID	¿Y ahora como se limpia la basura espacial?	04/03/2014	TEKNLIFE	Civil society		Spain

Section B (Confidential or public: confidential information marked clearly)

LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, UTILITY MODELS, ETC.					
Type of IP Rights	Confidential	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant(s) (as on the application)
Registered designs	No		M5370/2014	Kilaps	Gonzalo Sánchez Arriaga Daniel Pastor Moreno
Registered designs	No		M5377/2014	BETsMA	Gonzalo Sánchez Arriaga S. Bayajid Khan Antonio Sánchez Torres Francisco García de Quiros Jose A. Carrasco Roland Rosta John D. Williams Derek Blash

OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND								
Type of Exploitable Foreground	Description of Exploitable Foreground	Confidential	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner and Other Beneficiary(s) involved
Commercial exploitation of R&D results	In WP52 the software called BETsMA was developed. It carries out preliminary design of deorbiting missions with electrodynamic tethers.	No		BETsMA.	Space Agencies and industry	After registering, licenses will be distributed by UPM.	Application for a Registered Design is under submission (M5377/2014)	UPM, CSU, DLR and emxys
Commercial exploitation of R&D results	In WP12 the software called Kilaps was developed. The program computes the non-stationary current collection by Langmuir probes in flowing plasmas	No		Kilaps	Space agencies, plasma industry	After registering, licenses will be distributed by UPM	Application for a Registered Design is under submission (M5370/2014)	UPM
Commercial exploitation of R&D results	Hollow Cathode Plasma Contactor	Yes		Hollow Cathode Plasma Contactor	Space Technology	Start in 2014	Patent requested on 1 April 2014	Colorado State University
Commercial exploitation of R&D results	The Foreground consists in an ECU (Electrical control unit) for deorbit systems based in Electrodynamic tethers. The development resulted from the tasks related with Work Packages 22 and 32.??	Yes		ECU for Electrodynamic Tethers??	Space industry and Agencies addressing debris mitigation	1 year AFTER registering of IP	IP protection strategy currently under consideration	EMXYS
Commercial exploitation of R&D results	As a result of WP43, a complete simulator of tether dynamics during deployment was developed in order to test the BETs deployment system. Such a system can	No		Tether deployment simulator	R&D and industry Space partners working in tether deployment systems	1 year AFTER the end of BETs project	Different protection models are being currently considered	EMXYS

	be used to simulate the dynamics applied to the tether during the different phases of the mission, constituting a valuable test and validation tool for researchers and developers of tether deployment systems.							
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ADDITIONAL TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND	
Description of Exploitable Foreground	Explain of the Exploitable Foreground
In WP52 the software called BETsMA was developed. It carries out preliminary design of deorbiting missions with electrodynamic tethers.	BETsMA licenses will be sold by UPM after register (expected in few months). The code was design for both experts and beginners in tether technology. User interface and visualization tool are integrated in the software. Space agencies, companies and research groups will carry out with BETsMA preliminary misión design of deorbiting missions with bare tethers. In particular, the software provides the optimal tether geometry for a given misión and its cost in terms of mass.
In WP12 the software called Kilaps was developed. The program computes the non-stationary current collection by Langmuir probes in flowing plasmas	Kilaps licenses will be sold by UPM after register (expected in few months). Kilaps is the first direct Vlasov code aimed at Langmuir probes and space electrodynamic tethers. It is a helpful tool for the characterization of thes devices. Space agencies interested on spacecraft-plasma interactions and companies or research groups on plasma physics are potential clients.
Hollow Cathode Plasma Contactor	Colorado State University is planning to file a patent during April 2014 for a Plasma Contactor Hollow Cathode for Space Tether Applications
The Foreground consists in an ECU (Electrical control unit) for deorbit systems based in Electrodynamic tethers. The development resulted from the tasks related with Work Packages 22 and 32.??	emxys is considering file for protection of foreground in Current Control Modules
As a result of WP43, a complete simulator of tether dynamics during deployment was developed in order to test the BETs deployment system. Such a system can be used to simulate the dynamics applied to the tether during the different phases of the mission, constituting a valuable test and validation tool for	emxys is considering file for protection of foreground in Deployment Test Set-up

researchers and developers of their deployment systems.

4.3 Report on societal implications

B. Ethics

1. Did your project undergo an Ethics Review (and/or Screening)?

No

If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final reports?

2. Please indicate whether your project involved any of the following issues :

RESEARCH ON HUMANS

Did the project involve children?

No

Did the project involve patients?

No

Did the project involve persons not able to consent?

No

Did the project involve adult healthy volunteers?

No

Did the project involve Human genetic material?

No

Did the project involve Human biological samples?

No

Did the project involve Human data collection?

No

RESEARCH ON HUMAN EMBRYO/FOETUS

Did the project involve Human Embryos?

No

Did the project involve Human Foetal Tissue / Cells?

No

Did the project involve Human Embryonic Stem Cells (hESCs)?

No

Did the project on human Embryonic Stem Cells involve cells in culture?

No

Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?

No

PRIVACY

Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?

No

Did the project involve tracking the location or observation of people?

No

RESEARCH ON ANIMALS

Did the project involve research on animals?	No
Were those animals transgenic small laboratory animals?	No
Were those animals transgenic farm animals?	No
Were those animals cloned farm animals?	No
Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
Did the project involve the use of local resources (genetic, animal, plant etc)?	No
Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
Research having direct military use	No
Research having potential for terrorist abuse	No

C. Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	0	14
Experienced researchers (i.e. PhD holders)	5	19
PhD student	2	8
Other	4	16

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	1
Of which, indicate the number of men:	1

D. Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project ?	No
6. Which of the following actions did you carry out and how effective were they?	
Design and implement an equal opportunity policy	Not Applicable
Set targets to achieve a gender balance in the workforce	Not Applicable
Organise conferences and workshops on gender	Not Applicable
Actions to improve work-life balance	Not Applicable
Other:	
7. Was there a gender dimension associated with the research content - i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?	No
If yes, please specify:	

E. Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?	Yes
If yes, please specify:	XII & XIII Madrid semana de la Ciencia
9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?	Yes

F. Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?	
Main discipline:	2.3 Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)
Associated discipline:	1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

Associated discipline:	2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
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G. Engaging with Civil society and policy makers

11a. Did your project engage with societal actors beyond the research community? (if 'No', go to Question 14)	Yes
11b. If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?	Yes, in communicating /disseminating / using the results of the project
11c. In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	No
12. Did you engage with government / public bodies or policy makers (including international organisations)	No
13a. Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?	No

H. Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	28
To how many of these is open access provided?	7
How many of these are published in open access journals?	7
How many of these are published in open repositories?	0
To how many of these is open access not provided?	21
Please check all applicable reasons for not providing open access:	
publisher's licensing agreement would not permit publishing in a repository	Yes
no suitable repository available	No
no suitable open access journal available	Yes
no funds available to publish in an open access journal	No
lack of time and resources	No
lack of information on open access	No

If other - please specify	
15. How many new patent applications ('priority filings') have been made? ("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).	0
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	
Trademark	0
Registered design	2
Other	0
17. How many spin-off companies were created / are planned as a direct result of the project?	0
Indicate the approximate number of additional jobs in these companies:	0
18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:	Difficult to estimate / not possible to quantify, In small and medium-sized enterprises
19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (FTE = one person working fulltime for a year) jobs:	0Difficult to estimate / not possible to quantify

I. Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?	No
21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?	Yes
22. Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?	
Press Release	Yes
Media briefing	No
TV coverage / report	No
Radio coverage / report	Yes
Brochures /posters / flyers	Yes
DVD /Film /Multimedia	No

Coverage in specialist press	Yes
Coverage in general (non-specialist) press	Yes
Coverage in national press	Yes
Coverage in international press	Yes
Website for the general public / internet	Yes
Event targeting general public (festival, conference, exhibition, science café)	Yes

23. In which languages are the information products for the general public produced?

Language of the coordinator	Yes
Other language(s)	No
English	Yes

Attachments	HC.wmv, Boceto_A4.pdf, Poster_Xin.pdf, Poster_Introduccion.pdf, Poster_BETs.pdf, Poster_Gonzalo_II.pdf, Poster_Emxys.pdf
Grant Agreement number:	262972
Project acronym:	BETs
Project title:	Propellantless deorbiting of space debris by bare electrodynamic tethers
Funding Scheme:	FP7-CP
Project starting date:	01/11/2010
Project end date:	31/01/2014
Name of the scientific representative of the project's coordinator and organisation:	Prof. Juan R. Sanmartin UNIVERSIDAD POLITECNICA DE MADRID
Name	
Date	

This declaration was visaed electronically by Juan SANMARTIN (ECAS user name nsanmaju) on